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EFFECTS OF SUBSTRATE SIZE COMPOSITION ON SURVIVAL OF KOKANEE SALMON AND CUTTHROAT AND RAINBOW TROUT

By

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ABSTRACT

The effect of spawning gravel size composition on survival of kokanee salmon (*Oncorhynchus nerka*), cutthroat trout (*Salmo clarki*), and rainbow trout (*Salmo gairdneri*) embryos was assessed in laboratory troughs. Survival rates of the three species were mainly related to the percentage of particles less than 0.85 mm in diameter. Particles 0.85 to 9.5 mm had relatively little effect on survival. Fry of all three species emerged earlier from gravels with a high proportion of fine sediment than from those with relatively small amounts of fine sediment.

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INTRODUCTION

This report contains the results of laboratory tests relating embryo survival to substrate composition for kokanee salmon (Oncorhynchus nerka) and cutthroat (Salmo clarki) and rainbow (Salmo gairdneri) trout in 1982 and 1983. Results of prior project work to develop the method of relating embryo survival to substrate composition and measure survival rates for chinook salmon (Oncorhynchus tschawytscha) and steelhead trout (Salmo gairdneri) is reported in earlier project reports and in Tappel and Bjornn (1983).

Effects of fine sediment on salmonid survival have been assessed, but there is little agreement on which particle size classes should be classified as fine sediment. Embryo survival has been negatively correlated with fine sediment of various sizes: <0.85 mm, 1 to 3 mm, <3.3 mm, <6.35 mm, and 9.55 mm (Koski 1966, Bjornn 1969, Hall and Lantz 1969, Koski 1975, Tagart 1976, Cederholm et al 1981, and Scrivener and Brownlee 1981). These varied definitions of "fine" sediment have hampered efforts to evaluate suitability of spawning areas based on substrate composition.

Tappel and Bjornn (1983) suggest that salmonid embryo survival is likely affected by more than a particular particle size class in the spawning substrate. They developed a new method of describing natural assemblages of spawning gravel and related it to embryo survival.

METHODS

We tested kokanee salmon and cutthroat and rainbow trout embryo survival using similar methods and substrate mixtures and the same experimental troughs as Tappel and Bjornn (1983).

Gravel Mixtures

Each experimental gravel mixture was given a label corresponding to the percentage of gravel smaller than 9.5 mm and the percentage smaller than 0.85 mm (Table 1). For example, the gravel mixture labeled 30:2, had 30% of the mixture smaller than 9.5 mm in diameter and 2% smaller than 0.85 mm. There were either two or three replicates for each of the 15 gravel mixtures. Gravel mixtures tested included the range of size compositions found in natural streams (Figure 1). The shaded area delineates the range of gravel size composition found in salmon spawning areas in the Clearwater River, Washington and the South Fork Salmon River, Idaho (Tappel and Bjornn 1983).

Laboratory Tests

Water hardened kokanee salmon, eyed cutthroat trout, and water hardened rainbow trout embryos were transported to the

Table 1. Size composition (percentage smaller than a given size) of gravel mixtures used in embryo survival tests, 1982-1983.

Gravel mixture label	Particle size (mm)								
	50.8	25.4	12.7	9.50	6.35	4.76	1.70	0.85	0.42
0: 0	99.4	73.7	4.3	0	0	0	0	0	0
10: 4	99.5	76.3	13.8	10.0	9.9	9.4	5.9	3.9	2.2
20: 8	99.5	79.0	23.4	20.0	19.8	18.7	11.7	7.8	4.4
30:12	99.6	81.6	32.9	30.0	29.6	28.1	17.6	11.7	6.6
40:16	99.6	84.2	42.5	40.0	39.5	37.5	23.4	15.6	8.8
50:20	99.7	86.8	52.1	50.0	49.4	46.8	29.3	19.5	11.0
15: 4	99.5	77.6	18.6	15.0	14.1	12.2	5.7	3.5	2.0
25: 6	99.6	80.3	23.2	25.0	23.4	20.3	9.5	5.8	3.4
35: 8	99.6	82.9	37.7	35.0	32.8	28.4	13.3	8.2	4.8
45:10	99.7	85.5	47.3	45.0	42.2	36.5	17.1	10.5	6.2
55:13	99.7	88.2	56.9	55.0	51.6	44.7	20.9	12.9	7.5
10: 1	99.5	76.3	13.8	10.0	9.0	7.1	1.8	0.7	0.4
20: 1	99.5	79.0	23.4	20.0	18.0	14.2	3.5	1.4	0.9
30: 2	99.6	81.6	32.9	30.0	26.9	21.3	5.2	2.0	1.3
40: 3	99.6	84.2	42.5	40.0	35.9	28.4	7.0	2.7	1.7

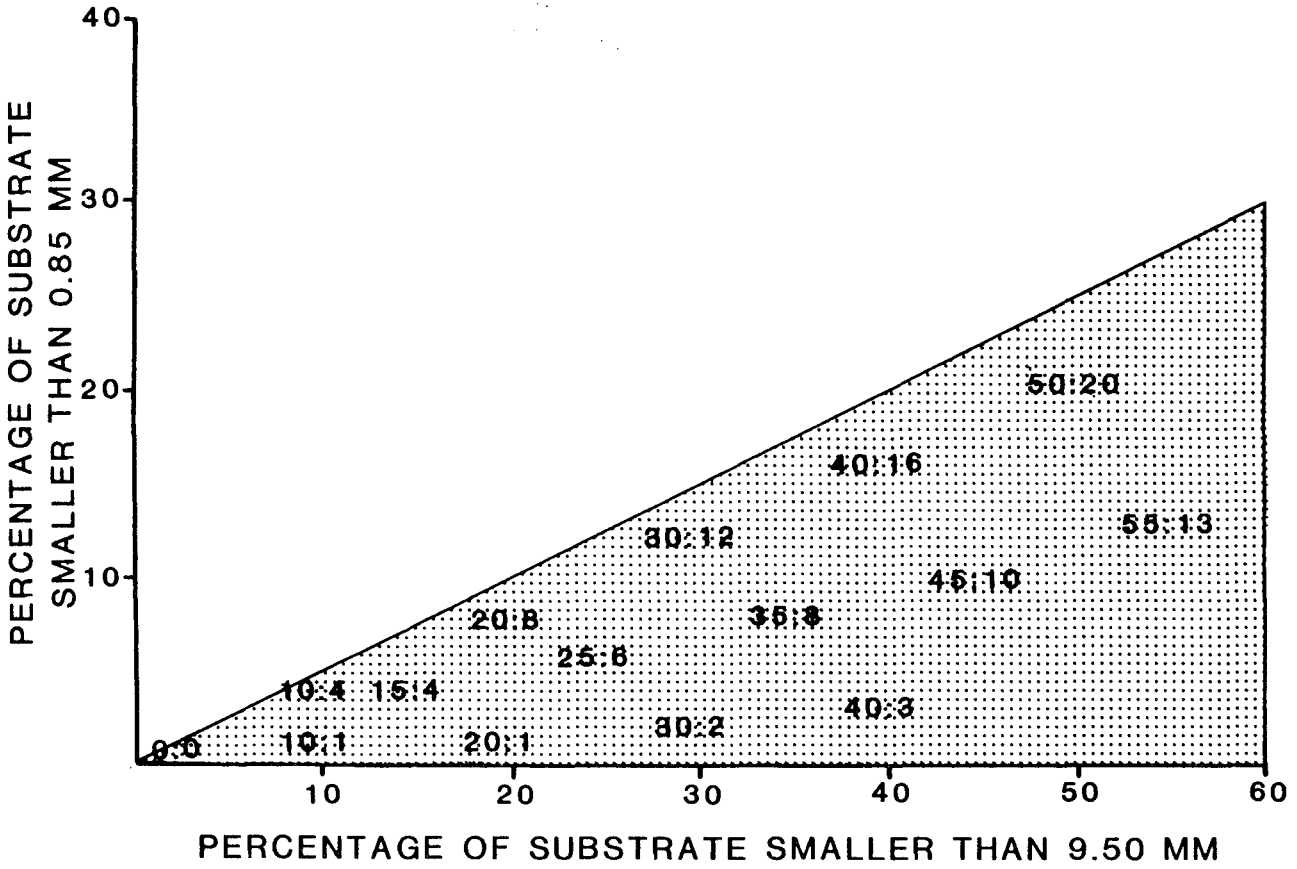


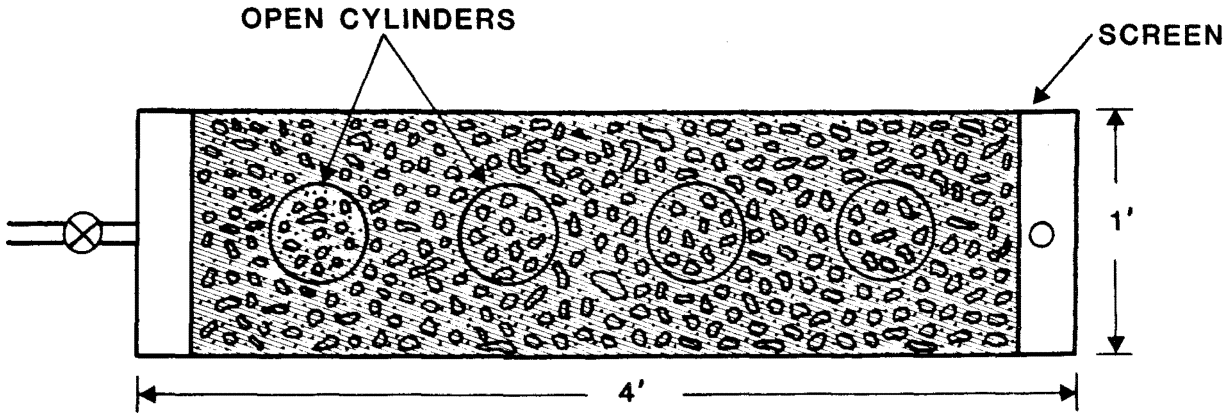
Figure 1. Experimental gravel mixtures (indicated by numerals) versus spawning substrate (shaded area). Assignment of labels (0:0, 20:8, etc.) corresponds to respective experimental gravel compositions from Tappel and Bjornn (1983).

University of Idaho on January 6, June 16, and December 3, 1982, respectively. The kokanee salmon and cutthroat trout embryos were obtained from Clark Fork State Fish Hatchery, Idaho. Rainbow trout embryos were obtained from Trout Lodge, a commercial hatchery near Soap Lake, Washington. Upon arrival at the University of Idaho all embryos were placed in experimental troughs and Heath incubators. We used the same experimental troughs (Figure 2) as Tappel and Bjornn (1983). Water flow and gradient through each trough could be regulated individually.

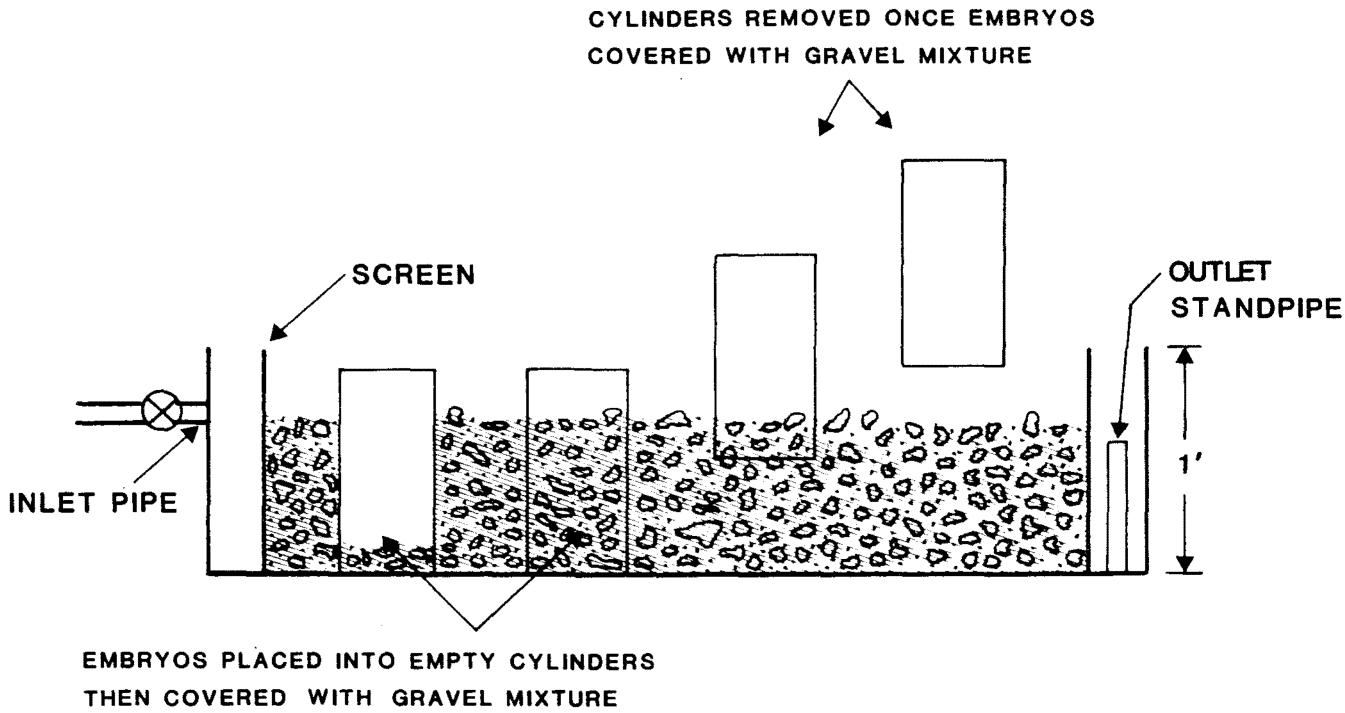
In each test, 100 fish embryos were divided equally and placed into four cylinders in each of the 40 experimental channels. Embryos were then covered with the gravel-sand mixture and cylinders removed leaving eggs buried (Figure 2). Eggs were also placed in a Heath incubator stack to observed survival of embryos not covered by gravel. Two channels without sediment smaller than 12.7 mm were used as control channels. Fry emerging from each channel were counted and removed. The tests were terminated when fry ceased emerging from the channel substrates.

Embryo Survival

Embryo survival was determined by dividing the number of fry emerging by the original number placed into each channel. To assess embryo mortality caused by something other than the



TOP VIEW



SIDE VIEW

Figure 2. One of 40 incubation troughs used to evaluate salmonid embryo survival-to-emergence in various gravel mixtures.

Table 2. Embryo survival in Heath incubator stack and channels without sediment smaller than 9.5 mm (n=2).

Species	Heath incubator			No-fines channels		
	Eggs no.	Fry no.	Survival (%)	Eggs no.	Fry no.	Survival (%)
Kokanee salmon	950	848	89.3	100	81	81.0
Cutthroat trout	772	57	92.6	100	88	88.0
Rainbow trout	2000	1794	89.7	100	75	75.0

sediment mixture we measured mortality in Heath incubator stacks and channels without sediments smaller than 9.5 mm (Table 2). Survival in the "no-fines" channels was less than the 95% rate we might have expected (Bjornn 1969, McCuddin 1977), an indication that some mortality resulted from handling of the eggs, incomplete fertilization, or other causes. Therefore, we adjusted survival rates observed in all channels by multiplying the observed survival rate by a ratio of expected survival (95%) divided by the average survival in test channels containing no sediment smaller than 9.5 mm (i.e., 81% for kokanee salmon)(Table 2).

We used stepwise regression to develop the best equation relating embryo survival to substrate size composition. Survival was correlated with two substrate sizes: 1) the percentage substrate smaller than 9.5 mm and 2) the percentage smaller than 0.85 mm. Second order and cross-product terms were included as variables to help detect any curvilinear relationships.

RESULTS

Survival of salmonid embryos ranged from 0.4 to 102.0% (Table 3). As the amount of fine sediment increased in the experimental gravel mixtures, embryo survival decreased (Figure 3).

Kokanee Salmon

Kokanee salmon embryos began hatching in the Heath incubator stacks on day 48 of the test. Most had hatched by day 55. The first fry began emerging from the experimental gravel mixtures on day 61, but peak emergence did not occur until day 81. The tests were terminated on day 107 (April 23, 1982).

The best third-order equation relating kokanee salmon embryo survival to gravel size composition was:

$$\text{Percent survival} = 104.76 - 4.87(S_{o.es}) + 0.235(S_{o.es})^2 - 0.099(S_{\varphi.s})(S_{o.es}).$$

This equation had an r^2 value of 0.93.

Cutthroat trout

Cutthroat trout embryos began hatching in the incubators on day 5 of the test. This short time span was a result of the developmental stage the embryos were in when received

Table 3. Mean adjusted embryo survival in different gravel mixtures for several salmonid species (number of replicate channels in parenthesis).

Gravel mixture label	Species				
	Kokanee salmon	Cutthroat trout	Rainbow trout	Steelhead trout	Chinook salmon
0: 0	95.0 (2)	95.0 (2)	95.0 (2)	93.0 (2)	96.0 (2)
10: 4	99.7 (3)	73.7 (3)	92.5 (2)	87.0 (3)	99.0 (2)
20: 8	64.5 (3)	18.0 (3)	33.2 (3)	86.0 (3)	97.0 (3)
30:12	32.8 (3)	0.7 (3)	7.2 (3)	59.0 (3)	88.0 (3)
40:16	16.1 (3)	0.4 (3)	3.0 (3)	14.0 (3)	32.0 (3)
50:20	10.6 (3)	2.5 (3)	10.2 (3)	10.0 (3)	6.0 (3)
15: 4	93.0 (3)	27.7 (3)	96.5 (3)	92.0 (3)	95.0 (3)
25: 6	79.8 (3)	46.1 (3)	64.2 (3)	91.0 (3)	93.0 (3)
35: 8	50.1 (3)	14.4 (3)	50.2 (3)	64.0 (3)	77.0 (3)
45:10	23.5 (3)	2.5 (3)	13.2 (3)	59.0 (3)	61.0 (3)
55:13	13.7 (3)	1.8 (3)	8.5 (3)	30.0 (3)	18.0 (3)
10: 1	93.2 (2)	91.2 (2)	96.3 (2)	94.0 (2)	95.0 (2)
20: 1	87.4 (2)	74.5 (2)	102.0 (2)	93.0 (2)	92.0 (2)
30: 2	83.3 (2)	56.7 (2)	91.2 (2)	95.0 (2)	88.0 (2)
40: 3	87.4 (2)	36.7 (2)	69.5 (2)	90.0 (2)	87.0 (2)

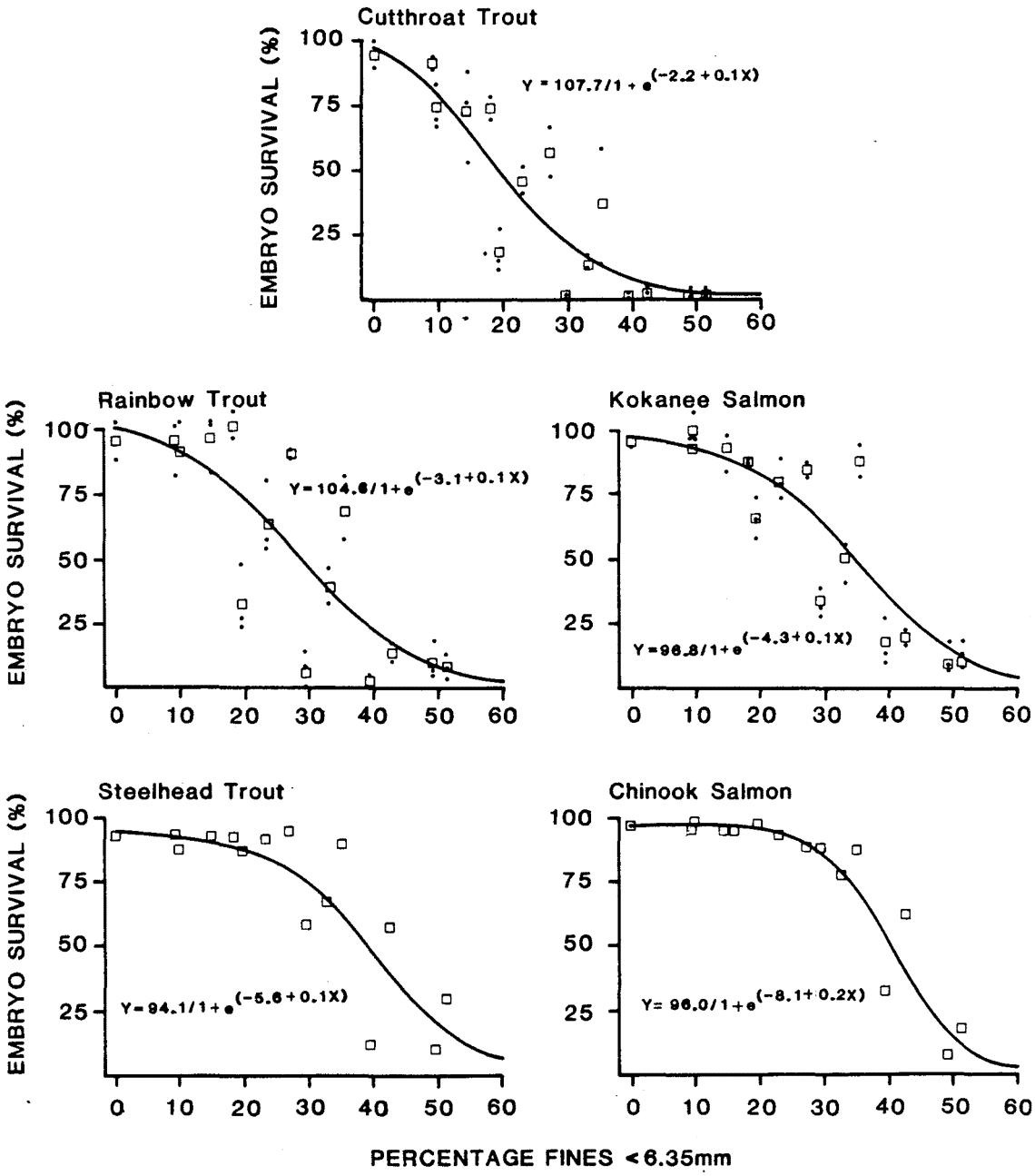


Figure 3. Relationship between embryo survival and percentage substrate smaller than 6.35 mm in size for several salmonid species. Chinook salmon and steelhead trout from Tappel and Bjornn (1983).

from the hatchery (eyed with approximately 514.5 temperature units). The first fry emerged from the experimental gravel mixtures on day 14 and peak emergence occurred on day 19 of the test. The test was terminated on day 34 (July 20, 1982).

For cutthroat trout embryos, the best equation relating survival to gravel size was:

$$\text{Percent survival} = 102.83 - 0.838(S_{\varphi.5}) - 9.29(S_{o.ss}) + 0.386(S_{o.ss})^2$$

This equation had an r^2 value of 0.94.

Rainbow trout

Rainbow trout embryos began hatching in the incubators on day 28 of the test. Fry began emerging from the experimental gravel mixtures on day 35 and peak emergence occurred on day 66. The test was terminated on day 69 (March 6, 1983).

For rainbow trout embryos, the best equation relating survival to gravel size composition was:

$$\text{Percent survival} = 113.58 - 10.77(S_{o.ss}) - 0.007(S_{\varphi.5})^2 + 0.301(S_{o.ss})^2.$$

This equation had an r^2 value of 0.92.

Using the above equations, embryo survival was predicted for a wide range of spawning substrates. "Three-dimensional"

Table 4. Coefficient of determination for linear regressions of individual particle size classes on survival of salmonid embryos. Particle size class is defined as the percentage of substrate smaller than a given sieve size.

Particle size class (mm)	r^2 value				
	Kokanee salmon	Cutthroat trout	Rainbow trout	Steelhead trout	Chinook salmon
9.50	0.68	0.73	0.60	0.56	0.66
6.35	0.74	0.77	0.65	0.62	0.70
4.76	0.82	0.82	0.73	0.71	0.74
1.70	0.91	0.81	0.86	0.86	0.74
0.85	0.89	0.77	0.85	0.86	0.70
0.42	0.90	0.79	0.86	0.86	0.71

Table 5. Rate of emergence (cumulative percentages) for rainbow and cutthroat trout and kokanee salmon in artificial channels filled with different sand-gravel mixtures, 1982-1983.

Incubation (week)[a]	Gravel mixtures: 55:13 50:20	45:10 40:16	35:8 30:12	50:3 25:6 20:8	10:1 20:1 30:2 15:4 10:4	0:0	All mixtures
Kokanee salmon							
1	4.8	0	0	0	0	0	0.1
2	30.6	17.8	10.3	7.9	7.5	9.3	9.3
3	64.5	64.4	58.7	57.7	65.6	73.5	63.4
4	90.3	89.1	85.4	88.6	91.3	95.0	90.1
5	93.5	99.0	97.7	95.6	95.6	98.8	96.2
6	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Cutthroat trout[b]							
1	12.5	0	0	1.8	0.8	0.6	1.0
2	37.5	0	11.1	10.5	6.3	6.9	7.5
3	100.0	14.3	52.8	26.3	23.2	30.6	26.1
4	-	71.4	69.4	47.4	51.0	65.3	53.3
5/6	-	85.7	86.1	92.5	92.3	97.1	92.8
7	-	100.0	100.0	100.0	100.0	100.0	100.0
Rainbow trout							
1	36.4	0	0	0	0	0	1.0
2	36.4	0	0	0	0	0	1.0
3	36.4	0	0	0	0	0	1.0
4	54.5	26.3	4.9	1.8	1.2	2.0	3.8
5	81.8	71.1	50.7	55.0	50.7	73.8	55.1
6	90.9	97.4	92.3	94.1	94.2	99.3	94.5
7	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Counted from day of first fry emergence.

[b] Daily cumulative percentages instead of weekly.

DISCUSSION

The relative position (horizontal, vertical, or diagonal to the x-axis) of the isolines (lines of equal survival) describe the effect different substrate sizes (<0.85 and 0.85 to 9.5 mm) have on embryo survival. Horizontal lines indicate that substrate less than 0.85 mm has the major effects on embryo survival. Vertical lines indicate that substrate between 0.85 and 9.5 mm in size effect embryo survival the most. Diagonal lines indicate that both substrate sizes (>0.85 and between 0.85 and 9.5 mm) effect embryo survival.

Lines of equal survival for cutthroat and rainbow trout and kokanee salmon were mostly horizontal, an indication that embryo survival was related mainly to substrate material less than 0.85 mm and only weakly related to larger substrate material. Survival of rainbow trout was particularly related to material less than 0.85 mm. Tappel and Bjornn (1983) found survival of steelhead trout embryos was also related mainly to substrate material less than 0.85 mm (Figure 5). Lines for equal survival for chinook salmon were more diagonal an indication that embryo survival was affected by sediments in both <0.85 and 0.85 to 9.5 mm size ranges.

We found that rainbow and cutthroat trout and kokanee salmon tolerated gravels with more fine particles than chinook salmon studied by Tappel and Bjornn (1983)(Table 4). They found that steelhead trout tolerated finer particle

sizes better than chinook salmon. Tappel and Bjornn (1983) attributed the lower survival of chinook salmon to their larger size at emergence. The larger the fry, the more difficulty they would have moving through the restricted gravel interstices during emergence. Other studies by Bjornn (1969) and Hall and Lantz (1969) produced similar results.

Tappel and Bjornn (1983) state that the most important outcome of their research was the development of 1) a new method for quantifying the effects of substrate size composition on salmonid embryo survival and 2) equations which relate embryo survival to size composition of the gravel for steelhead trout and chinook.

We have conducted similar tests and developed equations for 3 more salmonid species. These experiments as well as those by Tappel and Bjornn (1983) were conducted in a laboratory environment to control variables. Embryo survival in natural stream may or may not match the rates presented in these papers. The relationships presented are most useful for predicting the relative change in embryo survival rates that may occur if changes occur in spawning and incubation substrate.

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